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Uses and Misuses of Agricultural Pesticides in Africa: Neglected Public Health Threats for Workers and Population

Pouokam Guy Bertrand

Abstract

Pesticides are used in agriculture for their capacity to reduce pest and protect foods. Since their introduction in Africa by colonial masters, the use of these chemicals is constantly growing. Herbicides and insecticides are the two dominant categories. Although they are used in small quantities by farmers who own small exploitations, the frequency of their use, as well as overuses and misuses, constitutes serious factors of exposure and health risks. Farm workers are more vulnerable to occupational effects from pesticide inhalation and skin contacts. Failure to wear protective equipment and observe good agricultural practices explained health symptoms that are frequently experienced: eye and skin irritation, nausea, vomiting, and headache. Population is subject to chronic health effects due to repeated dietary intake of pesticides. Most consumed staple foods on the continent (cereals, vegetables, and fruits) have been found to be contaminated by one or multiple residues of pesticides. The level of residues is often higher than regulatory limits. Organization of surveillance programs to monitor concentration of pesticide residues remains inexistent in most countries, same for toxicovigilance systems to documented poisoning cases. Current data underline the need to carry out pesticide health risk assessment in order to appreciate the threats they pose for public health.

Keywords: pesticide, exposure, poisoning, residues, misuses

1. Introduction

Synthetic pesticides have been used in Africa since more than eight decades. They were probably introduced in the continent by colonial masters. From a historical point of view, the Public Health Act of the British government legislation, to protect human beings and regulate the use of pesticides by farmers in Kenya, was enacted in 1921 [1]. From that period till date, African countries continue to import pesticides from more advanced economies, mainly from European countries and recently from China.

The FAO statistical (FAOSTAT) database estimated that Africa have imported in 2016 pesticides for a value of 1590160.326 USD [2]. However, since few years, pesticides importation from China is constantly growing.

According to the export statistics from China Customs, export volume of pesticides (under HS code 29 and 38) during January to November in 2015, African markets represented 13.9% of the total export of pesticides from China and concerned 44 countries. Top 10 countries by export value are Nigeria, South Africa, Ghana, Ivory Coast, Egypt, Kenya, Cameroon, Tanzania, Ethiopia, and Guinea. The amount of export value for these top 10 countries constitutes 85.9% of the total export value to Africa from China, as shown in **Figure 1** [3].

Thousands of pesticides are imported, but the top 10 of most imported formulation products and active ingredients can be seen in **Table 1**.

Top 10 of most imported pesticides are mostly herbicides, followed by next 10 others products formulations which are mainly insecticides (chlorpyrifos, dichlorvos, dimethoate, abamectin, and cypermethrin).

It should be noted that in almost all countries, before their importation, pesticide products have to be homologated and authorized. Information are also provided to users on the purposes to which the products should be used, the dosage, their toxicological classes, first aid action to be taken in case of exposure, and even antidote in case of swallowed. Despite these precautions, Pouokam et al. [4] have reported several misuses in many countries and in particular in Cameroon.

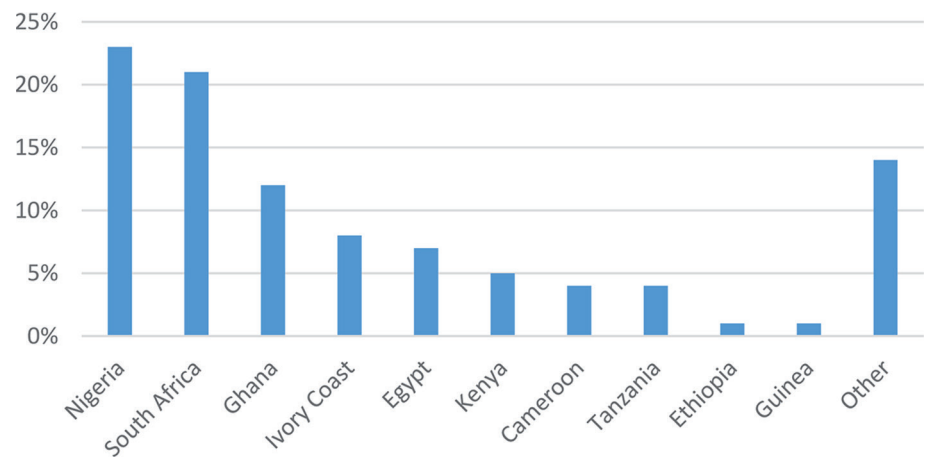


Figure 1.
Top 10 of pesticides export in Africa by export values (adapted from Agronews).

Formulation products	Export value (million USD)	Export volume (000 tons)
Glyphosate IPA 41% SL	93.82	50.82
Paraquat 200 g/L SL	62.53	25.97
Glyphosate 30%	20.07	10.44
Lambda-cyhalothrin 25 g/L EC	16.97	5.68
Mancozeb 80% WP	16.69	5.08
Glyphosate-monoammonium 75.7% SG	16.33	4.84
2,4-D-dimethylammonium 720 g/L SL	14.78	7.29
Mancozeb 64% + Metalaxyl 8% WP	11.61	1.80
Atrazine 80% WP	10.19	3.13
Imidacloprid 20% SL	8.13	1.91
Total	271.12	111.69

Table 1.
Top 10 of most imported formulation products and active ingredients (adapted from Agronews)

2. Uses and misuses of agricultural pesticides in Africa

Pesticide homologation procedures are established in all African countries. Procedures differ from one country to another, and the majority of pesticides formulations are homologated for uses in agriculture. In this chapter, we recall some key information concerning the number of pesticides formulations in distribution in the top 10 pesticides importers as indicated above.

In Cameroon, the official database from the Ministry of Agriculture counted up to 610 [4]. de Vos et al. reported 500 pesticide formulations used in South Africa Republic [5]. In 2011, the volume of imported pesticides in Ghana was 20,747 tons (9216 tons of insecticides, 8986 tons of herbicides, 2545 tons of fungicides) [6]. Ivory Coast and 13 other countries of the Permanent Interstate committee for Drought Control in the Sahel (CILSS), namely, Benin, Burkina Faso, Cap-Vert, Guinea, Gambia, Guinee-Bissau, Mali, Mauritania, Niger, Senegal, Tchad, and Togo, had adopted a common homologation procedures. The actual homologated list contains 438 pesticides formulations [7]. In 2016, Egypt consumed up to 10,600 metric tons of pesticides formulations [8]. Between July 2013 and June 2014, a total of 1182 different types of pesticides were registered in Tanzania, of which 11.2% were provisionally registered [9]. In 2017, 117 pesticide formulations were found to be homologated for used in Ethiopia, among which were 68 insecticides, 45 herbicides, and 4 fungicides [10].

Major uses of pesticides include agriculture, livestock development, and disease vectors control. Choice of pesticides depends on farmers' perception of its efficacy on pests, type and intensity of pests, crops growth stage and availability of pests, crops growth, and the availability of pesticide [11].

Supply channels of pesticides are both formal and informal and include:

- Authorized retail outlets of agricultural supply companies
- Government extension services
- Small-scale informal traders operating via local shops
- Itinerant peddlers visiting villages and weekly markets
- Bulk supplies from general markets in larger cities

A lot of misuses have also been reported in field farms because of (i) absence of clear instructions, (ii) illiteracy of farmers, (iii) lack of knowledge on risks from bad uses, (iv) uses of pesticides on crops for which the product was not homologated, and (v) difficulties to properly prepare the solution to be used, and poor respect of dosage [12].

In Benin Republic, previous studies, for example, revealed that farmers have been found to use insecticides registered for cotton protection on vegetables [12]. Moreover, Pouokam et al. observed the reuses of pesticides empty containers for drinking water and traditional wine. Other containers are washed and rinsed in rivers where populations fetch water for domestic uses [4].

Pesticide applications also vary with the type of crops and the type of equipment used, most farmers used knapsack and therefore carry the equipment on their back; others used atomizer, especially cocoa farmers. Because they did not respect wind direction, they often received pesticides vapor in their eyes and bodies part.

A detail analysis of all these practices gives insight on potential risk factors of pesticide exposures both for workers and nearby populations.

3. Use of predictive pesticides exposure models for occupational and para-occupational scenarios

Practice of agriculture in Africa is dominated by small farmers and family farmers whose one characteristic is that they operate in the informal sector. They are not registered and most of the time remains unknown by local authorities. This absence of clear statute for agricultural workers makes it difficult to organize and regulate the sector. Another consequence is the poor identification of exposure and poisoning cases.

Naveen Kumar et al. defined pesticides exposures as the contact of the pesticides with a surface or an organism. For a human, it means getting pesticides in or on the body [13].

Occupational and para-occupational exposures to agricultural pesticides in Africa remain as key concern that are unfortunately poorly addressed. Occupational exposure occurred in work places and concerned workers, while the definition of para-occupational exposure refers to exposure of people who may not formally work on farms but live on or near sprayed areas or participate in unpaid farmwork [14].

Several studies have found that farmers in their majority did not respect good practices recommended by international agencies and local authorities. Exposure to pesticides therefore often occurs while preparing the spray solutions, loading in the spray tank, and applying the pesticide [15]. Circumstances of poisoning vary: 27% during spraying, 20% by ingestion (drinking, food contaminated by hands that have been used to manipulate pesticides), 13% occurred at home, 7% in the kitchen, and 3% during fishing [4].

Occupational exposure concerned up to 30% of poisoning cases. Common occupational risk factors include (i) absence of personal protective equipment, (ii) spraying in a direction opposite to wind, (iii) aerial sprayed, (iv) pesticides pouring on the skin, (v) pesticides entering in the eyes, nose, and mouth, and (vi) respect of the indicated dosage.

Putting together these risk factors can help develop an occupational and para-occupational exposure model, in order to estimate exposure circumstances for a rapid and adequate case management.

The gravity and the seriousness of exposures will also depend on the toxicological class of the pesticides, the quantity of pesticides exposed, the frequency, and other vulnerability factors.

In many country of the continent, diseases caused by pesticides are not recognized as professional diseases and include in security health assessment measures to be carried out at workplaces, especially where agriculture mainly depends on family farmers and small exploitations.

There are many different pesticide exposure scenarios. Operator exposure monitoring is of great concern, because it is known that operators receive more pesticide exposure than any other type of worker due to their close proximity and amount of pesticide handled.

Models give the possibilities to estimate the exposure to an active substance or to rank exposure of one pesticide to others used in similar conditions. Model development required a clear formulation of the problem, as well as proper selection of key variables and indicators. First pesticide exposures models were developed around 1980, and since then, these models had been constantly refined. It should be recalled that models proposed are only as accurate as the input values fed into them. These models in some extent are complementary as they deal with various aspect and routes of pesticides exposures. **Table 2** is a summary of some exposure models involving human monitoring.

Models	Exposure predicts	Reference
SHEDS	Post-application residential exposure	(https://www.epa.gov/pesticide-science-and-assessing-pesticide-risks/models-pesticide-risk-assessment)
EPA residential	Adult applicator, adult and child post-application indoors and outdoors oral, dermal, and inhalation	US EPA 2012 (https://www.epa.gov/pesticide-science-and-assessing-pesticide-risks/standard-operating-procedures-residential-pesticide)
EUROPOEM II	European predictive operator exposure model based on underlying operator exposure studies	Van Hemmen, 2001 (https://academic.oup.com/annweh/article-abstract/37/5/541/167727)
AHETF	Mixer/loader and applicator dermal and inhalation exposure under long pants and long sleeve shirt with protective gloves	(https://archive.epa.gov/pesticides/news/web/html/occ-exposure-data.html)
AOEM	Predictive model for estimating operator exposure proposed for use in the EU	Guidance on the assessment for exposure for operators, workers, residents, and bystanders in risk assessment for plant protection products (https://www.efsa.europa.eu/fr/efsajournal/pub/3874)
OPPED	Occupational post-application exposure (e.g., harvesting, weeding, etc.)	(https://www.epa.gov/pesticide-science-and-assessing-pesticide-risks/models-pesticide-risk-assessment)
Calendex TM	Aggregated exposure that incorporated the probability of simultaneous exposures across multiple pathways	US EPA
CARES©	Dietary and residential (surface, hand to mouth, air)	(http://caresng.org/)
CONSEXPO	Exposure to substances from consumers products that are used indoors	(https://www.rivm.nl/en/consexpo)
Lifeline	Cumulative and aggregate exposure to pesticides in foods, drinking water, and residential use	(https://www.thelifelinegroup.org/)

Table 2.
Summary of some pesticides exposure models involving human monitoring (adapted from [16]).

Assumptions and parameters used to build these models are often based on pesticide uses in European and North American models, which do not properly correspond to various exposure scenarios found in Africa. Agricultural pesticides in Africa is mostly used in family farming, and some related features of exposures remains to be taken into account to fit existing models to ongoing practices on the continent.

4. Farmers perceptions and experience of harmful effects of pesticides

Pesticides toxicity varies from one molecule to another. Classification by the World Health Organization (WHO) is done according to pesticides lethal dose 50 (LD50). LD50 varies from slightly toxic (LD50 > 5000 mg/kg) to extremely toxic (LD50 < 50 mg/kg). Depending on circumstances, exposure can be done through breathing, eating, or drinking or by contact with the skin or eyes. During an investigation by Cheke et al., a medical examination was done on farmers in Ekiti

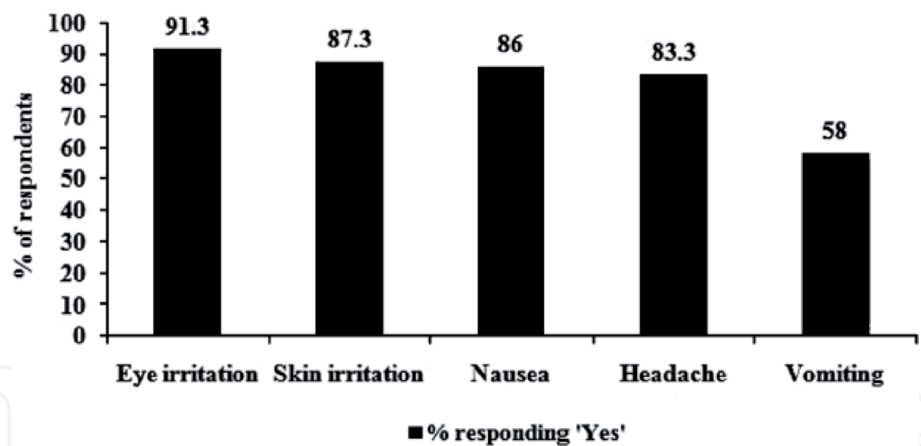


Figure 2.
Pesticide health symptoms experienced by farmers.

State, Nigeria, after taking their perceptions on any harmful effects they had experienced [17]. More than 91% of farmers reported to have suffered from pesticide-related health symptoms during or after applications. Symptoms were nausea, headache, vomiting, eye irritation, and skin problems, as shown in **Figure 2**.

In 2011, Mokhele determined the perceptions and awareness of farmworkers in Lesotho in South African Republic regarding the use of pesticides and the potential effects on their health. A total of 30 farmers from 6 farms participated [18]. The majority (85%) of farmworkers terminated their educational studies at the end of primary school. About 93% of farmworkers had received no training in the use of pesticides. A total of 52% of the farmworkers never wore rubber gloves when using or handling pesticides. All farmworkers in this study used a knapsack sprayer.

In the East African Rift (Ethiopia, Kenya, Tanzania, Uganda), Jacob de Boer et al. review literature about import, disposal, and health impacts of pesticides. They found out that in Ethiopia, few cases of poisoning have been reported [19]. Documented cases reported 81 pest control workers who were exposed to organochlorine pesticides (OCPs) (chlorpyrifos and profenofos) had lower cholinesterase levels after pesticide spraying. In Tanzania, data revealed that more than 50% of farmers have experienced headaches, excessive salivation, nausea, vomiting, and skin or eye irritation. Over 40% experienced dizziness, blurred vision, sleeplessness, and breathing difficulties, and over 20% reported tremors, diarrhea, chest pain, pain when urinating, fever, wheezing, or nosebleed.

In Kenya, Tsimbiri et al. testified that the main health impact of pesticides on residents and workers at Lake Naivasha in Kenya were headache and miserableness, followed by respiratory symptoms [20].

Apart from occupational and para-occupational exposures, pesticide dietary intake appears to be an overneglected issue. Even when good agricultural practices are followed, it is recognized that residues of pesticides remain on treated foods and agricultural products. The level of residues can be much higher in scenarios where pesticide misuses are numerous like in Africa.

5. Levels of pesticide residues in some highly consumed foods

In most African countries, pesticide residues are not of concerns in agricultural products sold at local markets, on the contrary to export products, which raises more attention. Residues on produce resulting from the inappropriate use of

N ^o	Country	Pesticide/active ingredient	Class	Year of analysis	Commodity	Sampling location	Residu level (average) (mg/kg)	MRL (mg/kg)	MRL codex (mg/kg)	Reference
1	Ghana	Chlorpyrifos	Insecticide	2012	Fresh tomatoes	Kumasi six main markets	0.046 ± 0.01	0.5	1	[21]
2	Nigeria	p,p'-DDT (dichlorodiphényltrichloroéthane)	Anti-vectorial	2011	Tomatoes	Farms	0.046 ± 0.010	0.1	—	[22]
3	Ghana	Cypermethrin	Insecticide	2012	Tomatoes	Kumasi six main markets	0.035 ± 0.005	0.5	0.2	[21]
4	Ghana	Diazinon	Insecticide	2012	Tomatoes	Kumasi six main markets	0.009 ± 0.003	0.5	0.5	[21]
5	Ghana	Dimethoate			Tomatoes	Kumasi six main markets	0.013 ± 0.009	0.02	NI	[21]
6	Ghana	Malathion	Insecticide		Tomatoes	Kumasi six main markets	0.038 ± 0.032	3.0	—	[21]
7	Egypt	Malathion	Insecticide	2014	Tomatoes	NI	0.025 ± 0.005	0.5	0.5	[23]
8	Egypt	L-Cyhalothrin	Insecticide	2014	Tomatoes	NI	0.070 ± 0.01	0.1	—	[23]
9	Tanzania	Chlorpyrifos	Insecticide	2016	Tomatoes	—	7.528*	1.0	1	[24]
10	Tanzania	Ridomil	Insecticide	2016	Tomatoes	—	2854.729*	0.5	NI*	[24] et
11	South Africa	Chlorpyrifos	Insecticide	2016	Carrots	Johannesburg Supermarkets	0.02	0.05	0.1	[25]
12	Nigeria	Lindane	Insecticide	2012	Beans	Lagos markets	0.192	—	NI	[26]
13	Nigeria	Malathion	Insecticide	2018	Rice	Ondo State	4.82 ± 0.001	—	NI	[27]
14	Nigeria	Carbofuran	Insecticide	2018	Rice	Ondo State	0.08 ± 0.001	—	1	[27]
15	Nigeria	Dichlorvos		2018	Wheat	—	0.15 ± 0.001	—	NI	[27]
16	Togo	Lindane	Insecticide	2012	Beans	—	0.01	—	—	[28]

N ^o	Country	Pesticide/active ingredient	Class	Year of analysis	Commodity	Sampling location	Residu level (average) (mg/kg)	MRL (mg/kg)	MRL codex (mg/kg)	Reference
17	Ethiopia	Cypermethrin	Insecticide	2014	Red pepper	Local markets	0.30*	—	0.1	[29]
18	Ethiopia	Cypermethrin	Insecticide	2014	Maize	Local markets	0.156*	—	0.05	[29]
19	Cameroon	Carbofuran	Insecticide	2010	Maize	Markets of northern regions	0.001	—	0.05	[30]
20	Cameroon	Lindane	Insecticide	2010	Cowpea	Markets of northern regions	0.1	—	—	[30]
NI: Not indicated										

Table 3.
Pesticide residue levels in some of highly consumed food items.

pesticides are however one of the most important food safety concerns. **Table 3** gives a snapshot of pesticide residue levels in foods from the 10 countries identified as main importers.

Table 3 shows just a quick example of the type of pesticide residues that can be found in foods sold in market places of the continent. In all countries cited in the table, we have not been able to find any database of pesticide residues in foods. We focus on top 10 African countries importing pesticides from China. Others pesticide residues have been detected in African food products during their export into the European markets and notified on the Rapid Alert System for Food and Feed (RASFF) portal; an example of ethephon is found in pineapples coming from South Africa. In that specific case, the level of ethephon detected was **7.2 mg/kg and was treated as serious** [31].

Although herbicides are massively used, residues most often found in food items are insecticides. This can be due to their late uses in the production or during food conservation, especially in grains and cereals. Residues in most consumed foods are a clear indication of the level of exposure of the population.

Vegetables and grains appeared to be more frequently contaminated with residues.

In addition, multiple contaminations by 2–10 different pesticide active ingredients are also frequent, raising an issue of cocktail effects for a mixture of pesticides. Pesticides in combination may be far more dangerous and more serious threats for public health. Previous studies done on animal models showed various cocktail effects. Many chemical families of compound are involved specifically in synergy, addition, potentiation, and antagonism when combined.

Regulations of residues differ with countries; some countries had set their own maximum residue limits (MRLs) for certain pesticides in selected foods, and others have decided to adopt Codex alimentarius MRL. In both cases, actual levels of residues are found often to exceed national and/or international set MRLs.

6. Implications for pesticides dietary exposures and health risks

Pesticide residues refer to the pesticides that may remain on or in food after they are applied to food crops. Exposure of the general population to these residues most commonly occurs through consumption of treated commodities. Many food commodities are concerned with the exposure to several pesticide chemicals, especially staple foods, making it complex to estimate the dietary intake of residues.

To more accurately appreciate the health risk of pesticide residue intake, many approaches can be used. All of them are based on the assessment of level of residues in food commodities and the quantity of food consumed. Apart from being used as a starting point for estimating consumer exposures, MRLs are used also as reference points to decide misuses and as trade standards.

The use of food commodity MRL is a convenient way to assess the theoretical maximum daily intake (TMDI). This approach considered the set MRL as the contamination level assuming that farmers applied good agricultural practices. Unfortunately, from previous reading, we have seen that a huge number of farmers do not respect good agricultural practices, suggesting a higher level of residues and a higher risk for consumers.

In the example of **Table 3**, we observed that certain residue levels are higher than the set MRLs.

In South African Republic, Dalvie and London investigated the presence of pesticide residues in wheat produced and imported in the country and their health risks. Eight different pesticides were detected in total. The most frequently detected pesticides were mercaptotion (99%), permethrin (19%), and chlorpyrifos (17%).

Nine (11%) samples exceeded the EU wheat. Risk index calculated was found to be lower in more than half of cases [32].

Determining exposure values based on pesticide residue levels and the food consumption is also possible using either the deterministic or probabilistic approach. The deterministic approach is simpler and based on single-point estimates for each variable in the model. On the other hands, probabilistic approach allows using all possible values for each variable to be taken into account, and each possible model outcome is weighted by the probability of its occurrence. Probabilistic is therefore advantageous in that all available data are used, the exposure estimate is presented as a distribution, and variability and uncertainty can be quantified. The deterministic approach may be used as a screening tool to identify problematic pesticides, followed by the probabilistic approach to see if the point estimate actually gives rise to concerns.

In Tanzania, Kimanya et al., in 2016, estimated deterministically the dietary pesticide exposure of population to three pesticides through consumption of fresh tomato. Pesticide levels were detected for permethrin (mean, 5.2899 mg/kg), chlorpyrifos (mean, 7.5281 mg/kg), and ridomil (mean, 2854.279 mg/kg) in 18% of samples. Health risk indices, determined as ratio of estimated daily intake to acceptable daily exposure, for chlorpyrifos, permethrin, and ridomil were greater than one, which implies that lifetime consumption of fresh tomatoes can pose health risk for chlorpyrifos, permethrin, and ridomil for population of Meru District [33].

7. Conclusion and perspectives

Synthetic pesticides have been used in Africa since they were introduced by colonial masters. Over the years, the quantities of pesticides used especially in agriculture have exponentially increased. These products are not manufactured in African countries, but mainly imported from developing economies. Products were previously imported from Europe but, since few years, are growingly coming from China. Herbicides and insecticides constitute the top 20 of imported pesticides.

Although pesticides are homologated before they can be used, their supply to farmers followed many channels among which some that are illegal, particularly when it comes to supply products in rural settings.

Moreover, a lot of misuses are still observed on the field. Good agricultural practices are not known by a great number of farmers and workers, increasing therefore risk factors of exposures and poisoning.

Farmers are frequently subjected to multiple exposures at workplace (inhalation, skin contact), while populations are exposed to pesticide residues found in the environment and accumulated in foods commodities. Estimating the level of human exposure for occupational and non-occupational scenarios remains a real challenge for risk assessors. A number of tools and techniques exist but do not fit to all situations, particularly in cases of misuses of pesticide applications. Predictive models have been designed to quickly capture and assess exposure cases, but these models remain to be improved to fit unusual practices by small farmers in rural areas of Africa.

Farmers are all aware of risks that pesticides can cause to their health; however, they remain reluctant in using protective equipment and to adopt preventive behavior. Most of them have reported to experience at workplaces symptoms of pesticide poisoning (eye irritation, skin irritation, nausea, headache, and vomiting).

Because of the absence of toxicovigilance systems, as well as surveillance and monitoring program, very few cases of pesticides poisoning have been documented. Epidemiological data are not known. Actual risk assessment is based on

the estimation of dietary intake of pesticides. These calculations showed frequent contamination of food items by pesticide residues, especially insecticides. The level of residues is often higher than national and international maximum residue limits, suggesting real public health threats for the whole population. In addition, cocktail and cumulative effects of multiple residues remain to be investigated.

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